AMERICAN UNIVERSITY OF BEIRUT
FACULTY OF ENGINEERING AND ARCHITECTURE

Computational Neuroscience
BMEN 609

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1. Course Administration

Instructor: Prof. Arij Daou
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2. Course Description [3 credits]

The human brain, perhaps the most complex, sophisticated, and complicated learning system, controls virtually every aspect of our behavior. Neuroscience is the study of the brain, and computational neuroscience divides this study into three subspecialties: neural coding, biophysics of neurons, and neural networks. This course will introduce engineers, physicists, computational scientists, mathematicians and other audiences to the neurosciences from the cellular level and the network level by giving a mathematical introduction to neural coding and dynamics. Basic techniques of modeling biophysics, excitable membranes, small network and large scale network systems will be introduced. The course begins with a consideration of mathematical models of excitable membranes, including the Hodgkin-Huxley model and simplifications such as the Morris-Lecar and FitzHugh-Nagumo models. It will provide hands-on laboratory experience in modeling membranes, neurons, and neural networks. The course explores the use of differential equations, numerical simulation, and graphical techniques for modeling compartmental and connectionist neural systems. The range of topics include simulations of electrical properties of membrane channels, single cells, neuronal networks, learning and memory models, stochastic models of ion channels, and models of synaptic transmission.

3. Time and Place

MW: 2:00 – 3:15
Place: MAMC 207

4. Prerequisites

BIOL 201, MATH 202, Knowledge of Matlab

5. Textbook and Software

- Material will be selected form book chapters, review articles and research journals.
- Recommended (but not required) books:
  - Peter Dayan & Larry Abbott. *Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems*. MIT Press, 2001
  - Irwin B. Levitan & Leonard K. Kaczmarek. *The Neuron: Cell and Molecular Biology*. Oxford University Press, 4th edition, 2015.
- Required software: Matlab

6. Course Objectives

- Define the basic cellular and network-level organization of neurons in selected systems.
- Understand the properties of cells that make up the nervous system including the propagation of electrical signals used for cellular communication, and relate the properties of individual cells to their function in organized neural circuits and systems.
- Construct biophysical models of neural systems that emulate electrical behavior of neurons and construct mathematical models that provide a probabilistic account of neural spiking activity.
- Perform mathematical analyses of data recorded during neurophysiology experiments to describe the principles of neural information coding in sensory and motor systems.
- Understand how neurons, and networks of neurons can be modeled mathematically by constructing mathematical models to describe neural activity/behavioral responses in terms of experimentally manipulated variables.
- Apply statistical techniques to examine the structure and distribution of experimental datasets; use unsupervised learning techniques for linear/nonlinear dimensionality reduction and clustering; visualize and interpret the latent structure in neuroscientific data.
- Formulate hypotheses captured by mathematical models, as possible explanations of observed relationships between experimental outcomes and manipulations.

7. Student Assessment

Assignments	**20%**
Paper Summaries	**10%**
Quizzes	**40%**
Final exam	**30%**

8. Moodle

Students are expected to check for updates on Moodle on a daily basis. Announcements, course handouts, and assignments will be available in “pdf” format from Moodle.

9. Course Topics

WEEK #	TOPICS
1	**Cellular Neuroanatomy** The prototypical neuron. Classifying neurons. Glia. Ionic basic of resting membrane potential. The action potential.
2	**Neurophysiology** Patch clamp. Voltage clamp. Extracellular single-unit and multi-unit recordings. Local field potentials. Nerve conduction studies.
3-4	**Electrophysiology of the Neuron** Mechanisms of action potential generation. Properties of ionic currents (I_{Na}, I_K, I_{Ca}, I_{AHP}, I_M…). Synaptic potentials. Electronics and physics backbones of intracellular recording.
5-6	**Theory and Modeling in Neuroscience** Computational neuroscience VS machine learning. Primer on linear algebra and probability. Phase plane analysis. Dynamical systems in neuroscience.
7	**Hodgkin-Huxley model: from Ion Channels to Mathematics** Ionic-based single and multiple compartment mathematical modeling of neurons, and networks of neurons.
8-10	**Biophysical Models of Neurons** Fitzhugh-Nagumo model. Phase plane analysis. Integrate and fire neurons. Resonate and fire neurons. Izhikevich models.
11-13	**Neural Coding: Temporal and Spatial** Receptive fields. Tuning Curves. Spike triggered averages. Firing rates. Oscillations, synchrony and cell assemblies. Time and place cells.
14-16	**Learning and Memory Models** Models of human memory. Associative and working memory. Linear oscillators. Hopfield networks. Supervised, unsupervised, Hebbian and reinforcement learning.
17-18	**Plasticity and Neural Networks** Spiking neural networks. LTP, STDP and LTD. Structural connectivity. Functional connectivity. Causal inference. Nonlinear dynamical systems.
19	**Neuroprosthetics: BCI and EEG** Overview and milestones of BCI and EEG. Physiological signals and components of BCI and EEG (signals acquisition, features extraction and translation …).

AUB strives to make learning experiences as accessible as possible. If you anticipate or experience academic barriers due to a disability (including mental health, chronic or temporary medical conditions), please inform me immediately so that we can privately discuss options. In order to help establish reasonable accommodations and facilitate a smooth accommodations process, you are encouraged to contact the Accessible Education Office: accessibility@aub.edu.lb; +961-1-350000, x3246; West Hall, 314